Met Office
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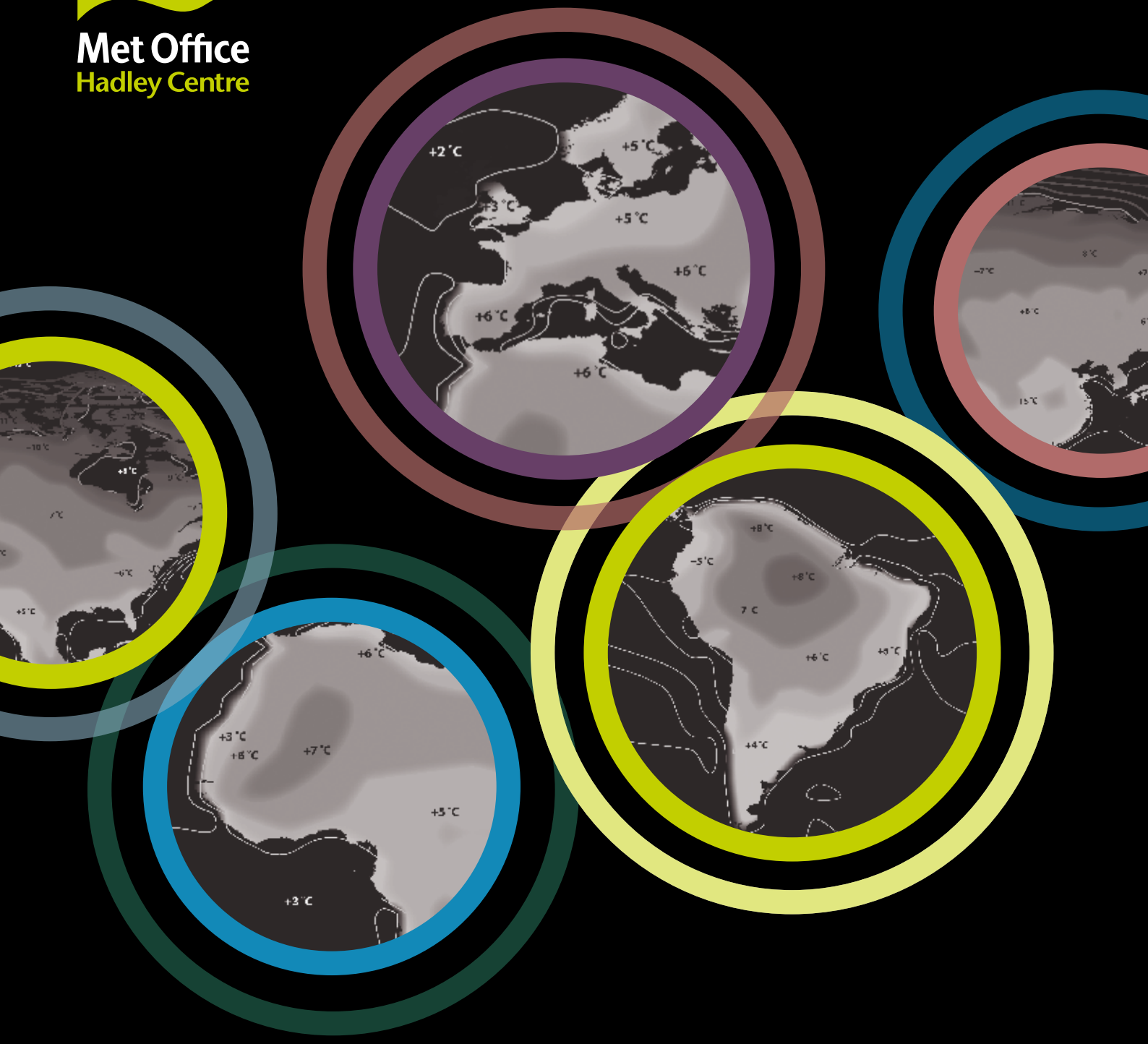


# Science

## Driving our response to climate change

Australian Government
Bureau of Meteorology

CSIRO

ECMWF

Environment Agency

NATURAL ENVIRONMENT RESEARCH COUNCIL

RESEARCH COUNCILS UK

UKaid
from the Department for International Development

UK Climate Impacts Programme

UNDP

Met Office working in partnership

# Informing choices

Some climate change is inevitable and it's essential we begin to put adaptation strategies in place. Properly applied science and research will inform our choices in dealing with climate change around the world, supporting sustainable development and global equity.

The climate modelling tools and results from the Met Office Hadley Centre can help. Some of these have already been used by scientists and planners to build capacity and inform decisions, particularly in the UK and some developing countries.

Climate change will affect all aspects of life — increasing risks to food security, water availability, infrastructure and human health. Meeting the challenges requires the best possible information with predictions at global, regional and local levels, and on timescales from the coming month to a century ahead. This information needs to be interpreted to highlight the real impacts, and combined with specific advice to help everyone prepare for the future.

The Met Office, working with a growing number of partners, is pioneering the use of climate science to provide solutions for some of these issues. Here, we highlight recent projects and research which are breaking new ground in this developing area.

"[Climate research] is of crucial importance in informing so many people around the world of the nature of the threat, the huge challenges we all face."

Prince Charles, Speaking at the Met Office HQ, September 2009

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# Avoiding dangerous climate change

It is clear from the work of the IPCC that if greenhouse gas emissions continue unconstrained we will be faced with rapid and irreversible climate change this century, with severe consequences for the natural world and human society. In order to avoid many of the most dangerous impacts, emissions must be reduced worldwide. This raises questions about what impacts we wish to avoid, the associated limit to climate change and the emission pathways that would need to be followed to achieve such limits.

The UK has started a research programme, called AVOID, to provide key advice to Government stakeholders on how to answer such questions. Led by the Met Office in a consortium with the Walker Institute, Tyndall Centre and Grantham Institute, the programme has already delivered a range of key findings.

The programme is funded by the UK's Department of Energy and Climate Change (DECC) and Department for the Environment, Food and Agriculture (Defra). Initial work has focused on the benefits of limiting warming to 2 °C above pre-industrial levels and emission scenarios that can achieve this limit.

The AVOID results show it is possible to restrict warming to 2 °C or less during the 21st century with at least a 50% probability.

## CAN WE AVOID DANGEROUS CLIMATE CHANGE AND ITS IMPACTS?

- AVOID shows that limiting global warming to 2 ˚C is possible but challenging. Early global action to reduce emissions increases our chance of remaining below this level.
- Reducing the risk of triggering accelerated or irreversible climate change is one of the strongest reasons for imposing stringent climate mitigation policies. Limiting future climate change reduces the risk of irreversible melting of the Greenland and Antarctic ice sheets and the release of large natural stores of methane from under parts of the ocean, which could cause further warming. It will also limit the climate-induced loss of tropical forests.
- Achieving an early peak in global emissions can help avoid impacts on many sectors later this century.
- For all mitigation scenarios, the majority of the benefits of mitigation will not be realised until several decades after emissions cuts begin. This is due to inertia in the climate system.
- Some impacts result from both increasing atmospheric $CO_2$ concentrations as well as changing climate. For instance, $CO_2$ increases plant growth, which may reduce the negative effects of climate change on plant yields. However, it also leads to greater ocean acidification, which — with increasing sea temperatures — can damage ocean ecosystems such as coral reefs. There is a significant regional variation in the direct impacts, but some indirect effects could be felt globally because of effects on global trade, migration and potential conflict over issues such as access to fertile land and water.
- Although stringent mitigation action to achieve a 2 ˚C target should prevent the most damaging effects of climate change, it will not avoid all climate impacts.

## HOW CAN WE STAY BELOW A WARMING OF 2 °C?

The AVOID results show it is possible to restrict warming to 2 °C or less during the 21st century with at least a 50% probability.

Figure 1 shows how the date of peak emissions, post-peak emission reduction rates, and ultimate temperature rise are related. The dashed lines show the predicted maximum temperature rise for five rates of a post-peak decrease in emissions (1–5%). The scale along the bottom is the year in which emissions peak. The scale at the left-hand side is the resulting temperature.

For example, the curve for a post peak emission reduction rate of 1% per year illustrates the likely global temperature for different peak dates. So we can see, even if emissions peak in 2016 and reduce at this rate we will not be able to keep temperatures below 2 °C. In fact the best we are likely to achieve is 3.5 °C, and delaying peak emissions until 2030 could see 4.5 °C. The slow emissions reduction in this scenario means emissions continue beyond 21st century, generating significantly more warming in the long-term. On the other hand in the far more challenging emission reductions scenario of 5% per year, it is possible to keep temperatures below 2 °C, but peak emissions would still have to happen by about 2020.

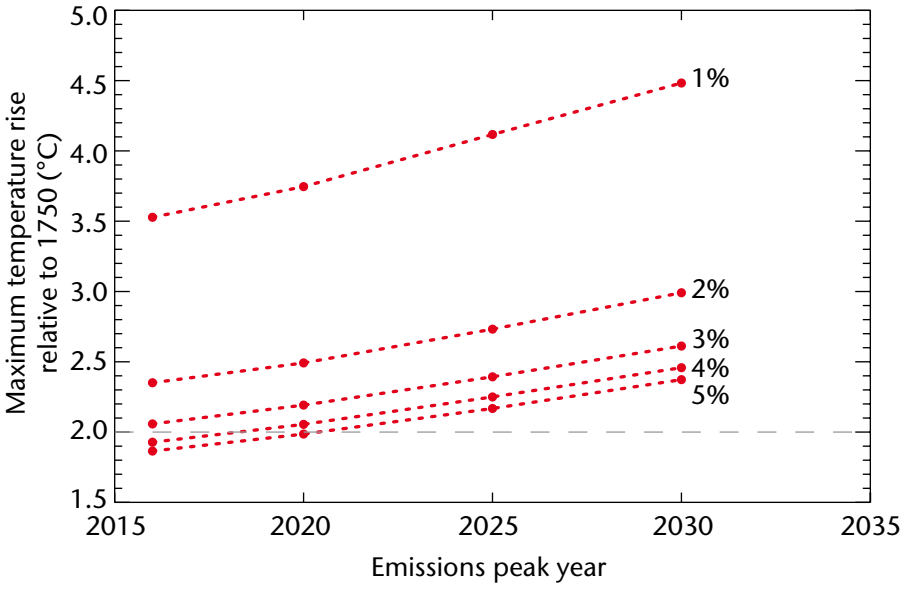



**Figure 1.** Which emission trajectory yields a temperature that remains below 2 °C, 3 °C or 4 °C with at least a 50% probability? The 2 °C target is taken here to mean 2 °C any time up to year 2500 relative to pre-industrial. The lines represent different post-peak reduction rates.

The study concludes that for a 50% chance of staying below 2 °C:

- If emissions peak early then we will have more flexibility to achieve a 2 °C goal, but emissions will still need to reduce by about 3% per year — even for a peak in 2016.
- There is some flexibility in the year of peak emissions (between 2014 and 2020). However, a later peak year would require more rapid reductions after the peak (at least 5% for 2020) and would also require a low or zero long-term level of emissions in the medium to long-term. This may be beyond economic and technological feasibility. There is thus a strong argument for early action.
- By 2020 total global annual emissions must be 50 $GtCO_2$ equivalent per year or less. Any more than this would require potentially unfeasibly large, long-term emission reductions. However, settling for emissions near this upper limit will reduce the flexibility in emissions targets in 2050 and still require rapid reductions post 2020.

In addition:

- Emissions after 2050 matter. For instance, an extra 100 years of $CO_2$ emissions at just a fifth of levels in 2000 could add more than 0.3 °C to peak warming.
- If we want a 90% chance of staying below 2 °C, we will need negative emissions and/or some geo-engineering intervention.

## WHAT ARE THE REGIONAL BENEFITS OF MITIGATION?

The AVOID programme has assessed the potential impacts of climate change with and without action to reduce emissions in order to identify the benefits of keeping warming to less than 2 °C up to 2100. The sectors covered include food security, agriculture, water resources, human health, biodiversity, and coastal systems.

Here we present results for three sectors: crop suitability (Figure 2), water stress (Figure 3, overleaf), and river (fluvial) flooding (Figure 4, overleaf). In each case, the top map shows the potential impact under the business as usual (IPCC SRES A1B) scenario by 2100. The bottom map illustrates the percentage of impact which could be avoided by a very ambitious mitigation scenario, where greenhouse gas emissions peak at 2016 and reduce by 5% per year thereafter. In each case it is clear that significant fractions of the impacts can be avoided, although some impacts will still be felt. These studies do not take into account the further reduction in damage that can be achieved through adaptation.

Climate change can increase the amount of land suitable for crop growth in high latitudes, but decreases suitability in many dry tropical and subtropical regions (due to lower moisture availability). Climate mitigation can have a big impact on this effect. For example, early emissions reductions lead to a reduction of more than 60% in the amount of land which would otherwise become unsuitable for crop growth by 2080.

Unmitigated climate change could see significant increases in the number of people affected by water shortages. Mitigation scenarios see this impact avoided in many areas, particularly in Central America, Africa (north, south and east) and in Europe. Benefits are also seen in the Middle East, India and the US.

Climate change could influence precipitation (rain, hail, sleet and snow) patterns and intensity, as well as glacial melt rates, which will change the flow of rivers across the globe. This increases the chance of fluvial flooding in many areas, particularly in south and east Asia. Mitigation reduces, but does not eliminate, the global exposure to flood risk from climate change.

Further information on the AVOID programme can be found at: **www.avoid.uk.net**

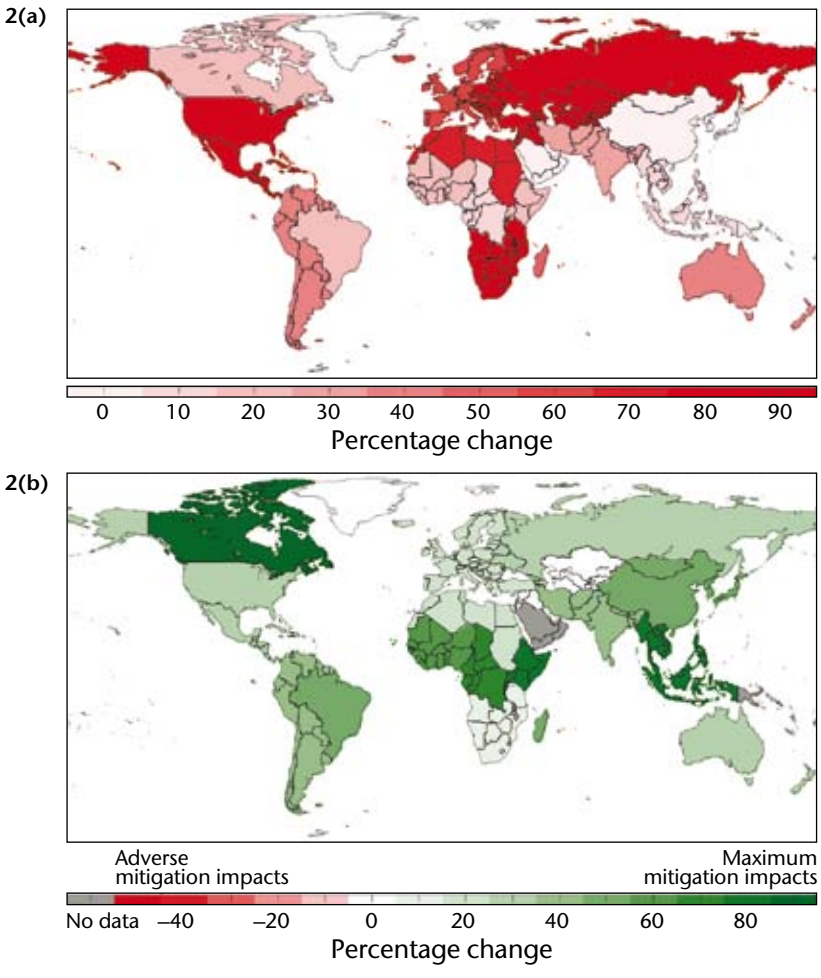
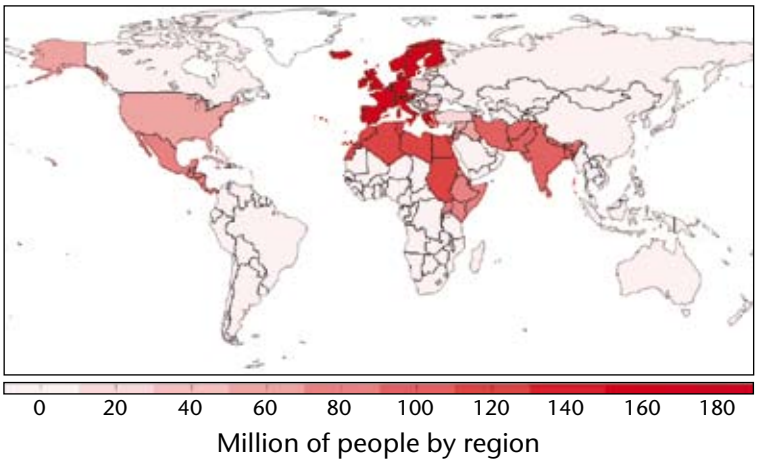



**Figure 2. (a)** Percentage of regional cropland with a decrease in crop suitability in an unmitigated world (A1B) by 2100. Note that for each region (mostly composed by multiple countries) this is the combined impact for places where crop suitability is decreasing. A corresponding map of increased suitability has non-zero values at middle and high latitudes, in particular where rising temperatures increase production potential. This analysis doesn't include the potentially positive impact of $CO_2$ on plant growth.
**(b)** Percentage of the impact avoided by early and rapid mitigation (2016 peak in emissions and 5% annual post-peak reduction rate) by 2100.

**Figure 3. (a)** Millions of people that experience increase in water resources stress by 2100 in an unmitigated world (A1B). Again there is a corresponding map of people that experience a decrease in water resource stress. For each region (mostly composed by multiple countries) the total number of people at risk for that region is shown. **(b)** Percentage of impact avoided by early and rapid mitigation (2016 peak in emissions and 5% annual post-peak reduction rate) by 2100.

3(a)




3(b)

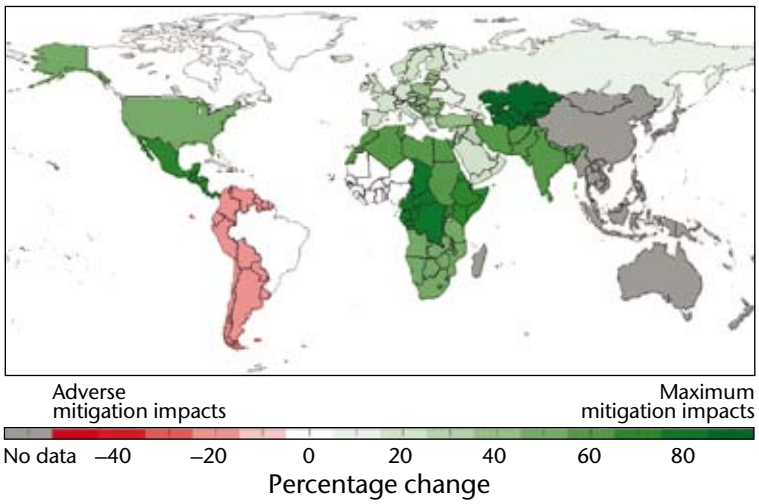
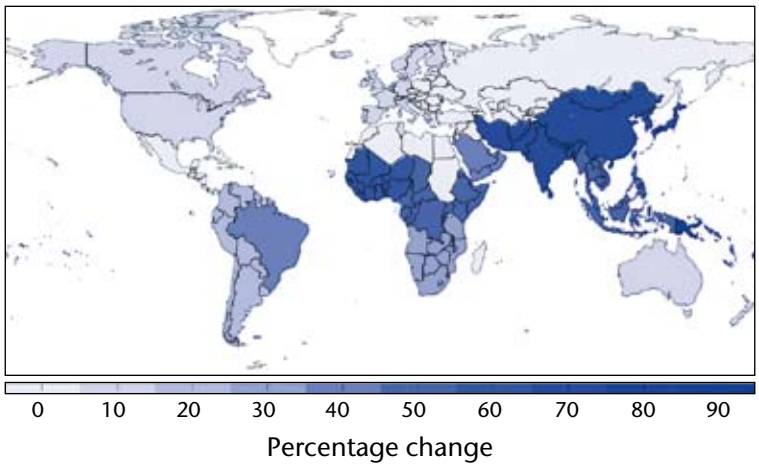
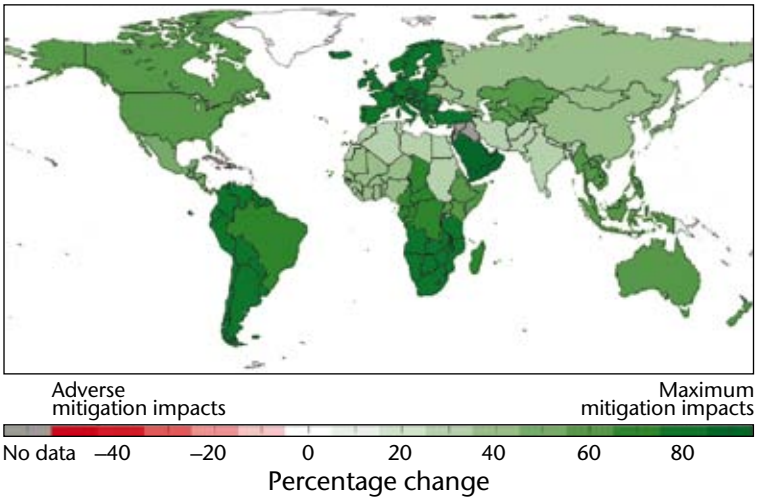



**Figure 4. (a)** Percentage of flood-prone population exposed to increase in river (fluvial) flood hazard by 2100 in an unmitigated world (A1B). Again there is a corresponding map of percentage of population exposed to decreased flood risk. Percentages are by region, which are mostly composed by multiple countries.
**(b)** Percentage of impact avoided by early and rapid mitigation (2016 peak in emissions and 5% annual post-peak reduction rate) by 2100.

4(a)




4(b)




Walker INSTITUTE

Tyndall Centre for Climate Change Research

Grantham Institute for climate change

DEPARTMENT OF ENERGY & CLIMATE CHANGE

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# ENSEMBLES

ENSEMBLES is a five-year research project on climate change and its impacts on Europe that is funded by the European Commission. Led by the Met Office and involving 66 partners, the project is the biggest ever integrated climate change research project. Using the most up to date models, ENSEMBLES has made significant advances in producing climate projections and assessing the impacts.

To date, the ENSEMBLES project has achieved:

- an ensemble prediction system, including earth-system feedback modelling, for the decades and century ahead;
- the first probabilistic climate projections for Europe;
- a clearer picture of the physical, chemical, biological and human-related feedbacks in the climate system and how to represent them in models;
- an assessment of the impact of climate change on agriculture (Figure 1), health, energy, water resources, insurance and other sectors;
- high-resolution climate observation datasets for Europe to validate the ensemble predictions.

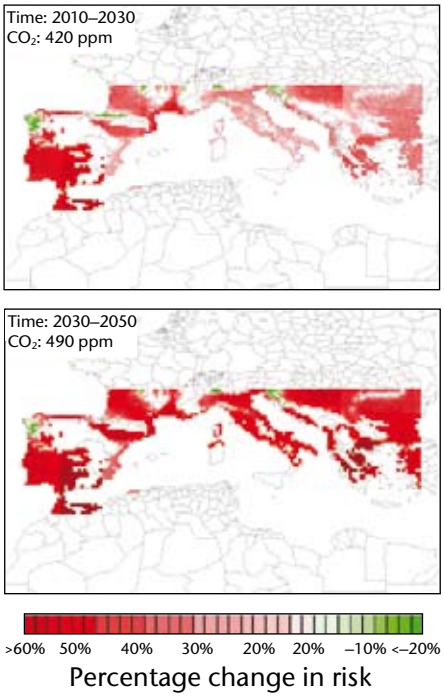



**Figure 1.** Plots showing risk of shortfall in durum wheat yield in the northern Mediterranean region for the periods **(a)** 2010–2030 and **(b)** 2030–2050 under the A1B emissions scenario (produced by the University of Florence). (van der Linden P, Mitchell JFB (eds.) 2009: ENSEMBLES: Climate Change and its Impacts: Summary of research and results from the ENSEMBLES project. Met Office Hadley Centre, FitzRoy Road, Exeter EX1 3PB, UK. 160pp).

## THE E1 MITIGATION SCENARIO

The project developed a new climate mitigation scenario, E1, which describes greenhouse gas emissions peaking at 44 billion tonnes of $CO_2$ equivalent by 2015 and atmospheric concentrations stabilising at 450 ppm (parts per million) in 2140. It also includes a detailed simulation of the global energy system and changes in land use. Ten European global climate models (GCMs) were run using E1, five of which included carbon-cycle feedbacks. This was the first time a mitigation scenario had been run on GCMs.

The starting point for constructing the scenario was the atmospheric concentrations of greenhouse gases. A reverse calculation then established the level of emissions that would achieve these concentrations. Socio-economic factors, such as population growth and renewable energy, were then used to construct the emissions profile. This methodology is similar to that under development by the Intergovernmental Panel on Climate Change for its Fifth Assessment Report.

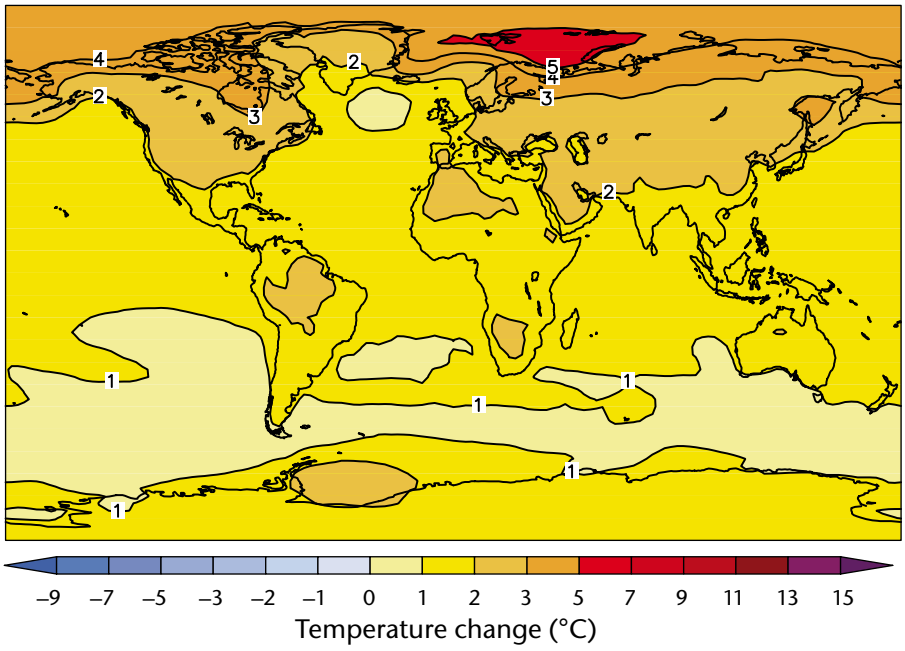
## FINDINGS

The impacts of climate change over the next 20–40 years depend mainly on greenhouse gases already in our atmosphere. The risks of a shortfall in durum wheat yield in southern Europe are projected to increase even over the next 20 years. Previously it was thought that $CO_2$ fertilisation would lead to increases in crop yield in the early part of the century, but these new results suggest the impacts of increasing temperature and decreasing rainfall will more than offset this.

The five ENSEMBLES GCMs which model carbon-cycle feedbacks were used to back-calculate man-made $CO_2$ emissions from land, ocean, and atmosphere carbon fluxes. They show that implied emissions of $CO_2$ to the atmosphere at the end of the century would need to be around zero to avoid temperature rises going beyond 2 °C. One model shows $CO_2$ emissions would need to be below zero, implying the need for carbon to be artificially removed from the atmosphere.

The results from the E1 mitigation scenario show the global average temperature rise remaining below 2 °C above pre-industrial levels in 2100, with regional variations (Figure 2). A temperature rise of no more than 2 °C is recognised as the safe level to avoid dangerous climate change.

**Figure 2.** Projected surface air-temperature changes (°C) under the E1 mitigation scenario, for the average of ten global climate models for 2070–2099 relative to the 1961–1990 average.

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# Geoengineering

- There has been very little research on geoengineering; and its potential benefits and risks, including unintended consequences, are poorly understood
- Met Office research into one potential geoengineering scheme has indicated it could cause significant side effects, with substantial reductions of rainfall in the Amazon rainforest
- Relying on geoengineering while allowing carbon emissions to continue could tie us in for centuries of commitment and force us to make far greater reductions in carbon emissions in the future

Geoengineering projects to artificially cool our planet have been put forward as possible solutions to global warming. These include schemes to reduce the amount of heat the Earth receives from the Sun, such as by seeding clouds to reflect more light, or forcing a reduction in $CO_2$ in our atmosphere.

A study by the Royal Society[1] recently found that unless future efforts to reduce greenhouse gas emissions are much more successful than they have been so far, geoengineering will be the only solution left to cool the planet. The research also concluded that geoengineering technologies are very likely to be technically possible and could be effective. However, many of the technologies are also potentially dangerous and unproven. The report identified major uncertainties regarding their effectiveness, costs and environmental impacts.

Met Office research to explore the potential impacts of geoengineering schemes has found that while they could indeed be effective, they could have serious side effects such as damaging important ecosystems.

One such Met Office study looked at 'seeding' clouds with sea-salt particles to make them brighter, thus reflecting more sunlight. A complex climate model was used to see what the long-term effect would be of using this geoengineering method off the west coasts of Southern Africa, South America, and North America — where there are extensive low-level clouds on a semi-permanent basis.

Seeding the clouds did have an impact, potentially slowing down global warming by up to 25 years. These impacts varied in each area, with changes to the South American cloud bank being the most efficient way to slow temperature increases.

However, there were significant climate side effects to changing the clouds.

[1] Geoengineering the climate: Science, governance and uncertainty (September 2009, Royal Society)

Figure 1 shows that seeding off the coast of Southern Africa and South America has the knock-on effect of changing rainfall around the world — particularly in the Amazon basin, reducing rainfall there by 30%. This could accelerate dieback of the Amazon rainforest, which is one of the world's major carbon stores, thus releasing huge amounts of carbon into the atmosphere and accelerating climate change.

This research underlines concerns about the potential feedbacks of geoengineering schemes. While there may be benefits in some areas, there may be detrimental impacts for significant regions of the world — raising questions about the practicality and long-term benefit of the projects.

Met Office research has also shown that relying on geoengineering to buy time in reducing $CO_2$ emissions could have serious implications. If we defer cutting carbon emissions from 10 to 40 years, the geoengineering schemes to offset this would potentially have to last for hundreds of years — putting a major burden on future generations.

Geoengineering reliance would also have the effect of storing up issues over our greenhouse gas emissions. Even by applying such techniques, any delay in cutting $CO_2$ emissions now would require much greater reductions in the future. To stabilise temperatures to avoid dangerous climate change we would have to cut global $CO_2$ emissions to zero or even have negative carbon emissions.

If the world were to continue emitting $CO_2$ in the future, we would be committed to using geoengineering indefinitely. This could also cause problems because if the geoengineering failed or was stopped too early the $CO_2$ in the atmosphere would take its effect, causing rapid climate change. Humans, wildlife and the environment would find it very difficult to adapt to the quick rise in surface temperatures. A further issue is that the continuing presence of $CO_2$ would affect ecosystems. Whilst this could improve plant productivity, it could have major implications for the ocean balance, causing continued ocean acidification.

Ultimately, geoengineering remains an embryonic area of science. While research is improving our understanding, there are still significant concerns and uncertainties which mean we cannot currently rely on such schemes to tackle climate change, particularly as an alternative to cutting $CO_2$ emissions.

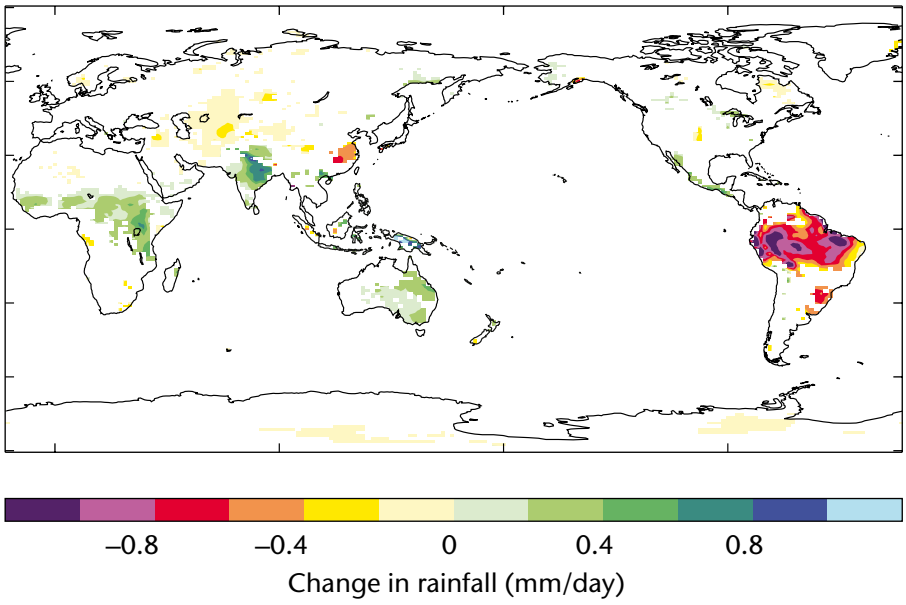


**Figure 1.** The impact of cloud brightening on the average 2030–2059 rainfall over land (millimetres per day) relative to an A1B scenario. White areas are where changes are not statistically significant (at the 5% level).

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